



Soil Moisture
Active Passive
Mission
SMAP

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Improved SMAP Dual-Channel Algorithm
for the Retrieval of Soil Moisture

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Outline

- Introduction and Motivation
 - Preliminary studies on roughness parameters and albedo ω
 - Implemented MDCA
 - Results and assessment
-



SMAP baseline model



τ - ω Model

$$TB_p^{sim} = T_s e_p \exp(-\tau_p \sec \theta) + T_c (1 - \omega_p) [1 - \exp(-\tau_p \sec \theta)] [1 + r_p \exp(-\tau_p \sec \theta)]$$

$$r_p(\theta) = [(1 - Q)r_p^*(\theta) + Qr_q^*(\theta)]e^{(-h \cos^N(\theta))} \quad p = (V/H)$$

Baseline models

Single Channel Algorithm (SCA)	Dual Channel Algorithm (DCA)
$F(SM) = [TB_p^{sim}(SM) - TB_p^{obs}]^2$ $\tau_p = \tau = b * VWC, VWC \text{ from climatology (NDVI)}$	$F_\tau(SM, \tau)$ $= [TB_V^{sim}(SM, \tau) - TB_V^{obs}]^2 + [TB_H^{sim}(SM, \tau) - TB_H^{obs}]^2$
$\omega_p = \omega$ $Q = 0$ $N = 2$ $h = 0.01 \text{ mm}^{-1} s, s \text{ is the root-mean-square of the surface height}$ $T_s = T_c$ $s, h \text{ and } \omega \text{ provided using the IGBP classification}$	

Baseline algorithm assessment over CVS



CVS	ubRMSD (m ³ /m ³)			Bias (m ³ /m ³)			RMSD (m ³ /m ³)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.040	0.040	0.055	-0.058	-0.013	0.036	0.070	0.042	0.065	0.627	0.644	0.592	138	141	141
Walnut Gulch	0.022	0.024	0.042	-0.013	0.018	0.052	0.025	0.030	0.067	0.816	0.834	0.815	158	188	188
TxSON	0.022	0.022	0.041	-0.067	-0.009	0.087	0.070	0.024	0.096	0.930	0.931	0.821	404	404	396
Fort Cobb	0.033	0.028	0.044	-0.083	-0.045	0.009	0.089	0.053	0.045	0.861	0.882	0.813	445	445	445
Little Washita	0.024	0.022	0.042	-0.062	-0.018	0.055	0.066	0.028	0.069	0.891	0.912	0.815	429	429	425
South Fork	0.062	0.055	0.055	-0.059	-0.038	-0.012	0.085	0.067	0.057	0.655	0.671	0.628	259	265	265
Little River	0.047	0.037	0.050	0.015	0.062	0.144	0.049	0.072	0.152	0.746	0.781	0.550	419	419	415
Kenaston	0.039	0.027	0.041	-0.026	0.006	0.057	0.046	0.028	0.070	0.753	0.800	0.585	187	187	187
Carman	0.086	0.064	0.066	-0.062	-0.047	-0.022	0.106	0.080	0.070	0.513	0.571	0.488	235	237	237
Monte Buey	0.074	0.049	0.043	-0.032	-0.016	-0.001	0.081	0.052	0.043	0.712	0.838	0.777	181	191	195
REMEDHUS	0.040	0.039	0.053	-0.016	0.012	0.038	0.043	0.041	0.065	0.850	0.846	0.818	343	348	348
Twente	0.072	0.054	0.059	0.023	0.045	0.078	0.076	0.071	0.098	0.879	0.889	0.751	330	347	347
HOBE	0.049	0.036	0.065	0.004	-0.003	0	0.049	0.036	0.065	0.723	0.860	0.755	117	117	117
MAHASRI	0.031	0.032	0.035	0	0.003	0.008	0.031	0.032	0.035	0.792	0.799	0.802	223	222	220
Yanco	0.045	0.039	0.046	-0.004	0.029	0.064	0.045	0.049	0.079	0.947	0.951	0.915	284	289	290
Mean Absolute Bias				0.035	0.024	0.044									
SMAP L2SMP_E Average V2	0.046	0.038	0.049	-0.029	-0.001	0.039	0.062	0.047	0.072	0.780	0.814	0.728			

- DCA shows high Bias, ubRMSD, RMSD and low correlation
- DCA does not meet requirements (< 0.04 m³/m³)
- Soil moisture DCA meets requirement in only one CVS



Preliminary study on roughness model

$$r_p(\theta) = [(1 - Q)r_p^*(\theta) + Qr_q^*(\theta)]e^{(-h \cos^N(\theta))}$$

Several studies have been done to calibrate the roughness parameters
 h, Q, N

- [1] J. Wigneron, A. Chanzy, Y. Kerr, H. Lawrence, J. Shi, M. Escorihuela, V. Mironov, A. Mialon, F. Demontoux, P. de Rosnay, and K. Saleh-Contell, "Evaluating an improved parameterization of the soil emission in L-MEB," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 49, No. 4, April 2011. DOI: 10.1109/TGRS.2010.2075935
- [2] H. Lawrence, J. Wigneron, F. Demontoux, A. Mialon, Y. H. Kerr, "Evaluating the semiempirical H - Q model used to calculate the L-band emissivity of a rough bare soil," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 51(7), pp. 4075–4084, July 2013. DOI: 10.1109/TGRS.2012.2226995
- [3] A. Mialon, J. P. Wigneron, P. D. Rosnay, M. J. Escorihuela, Y. H. Kerr, "Evaluating the L-MEB model from long-term microwave measurements over a roughfield, SMOSREX2006." *IEEE Trans. Geosci. Remote Sens.* 50, 1458–1467, 2012

- Several models relate h to the slope s/L (surface correlation length) adding a new unknown. Wigneron[1] proposed a model for h that depends on s , a parameter that SMAP already uses. This model was validated for several authors.[3]
- Several studies suggest that Q should be considered non-zero[2],[3]
- In view of those we look into the proposed model

$$h = \left(\frac{0.9437s}{0.8865s + 2.2913} \right)^6, \quad Q = 0.1771h, \quad N = 2.$$



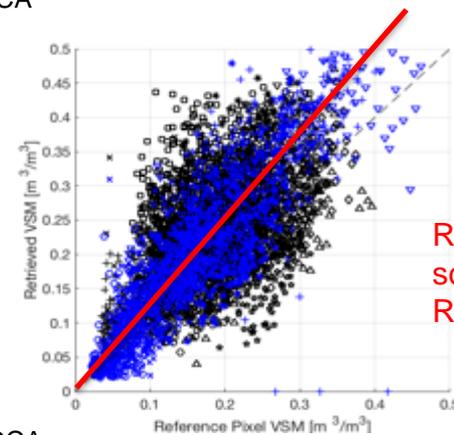
Roughness model

$$r_p(\theta) = [(1 - Q)r_p^*(\theta) + Qr_q^*(\theta)]e^{(-h \cos^N(\theta))}$$

$$h = \left(\frac{0.9437s}{0.8865s + 2.2913} \right)^6, \quad Q = 0.1771h, \quad N = 2. \quad \text{Wigner (2011), Lawrence (2013)}$$

Performance Metrics: DCA

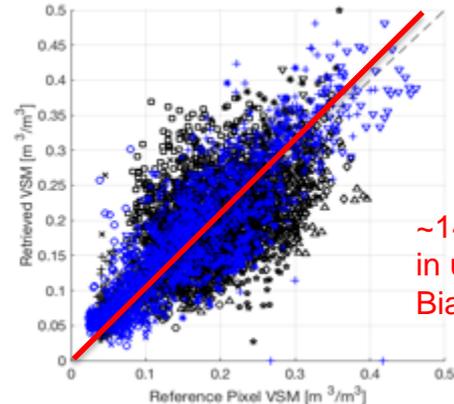
Ref Pixel	ubRMSE	Bias	RMSE	R	Slope	N
Reynolds Creek (0401-33-02)	0.055	0.035	0.065	0.602	0.768	144
Walnut Gulch (1601-33-02)	0.043	0.051	0.066	0.815	1.822	214
TxSON-Evett (4802-33-01)	0.041	0.087	0.096	0.822	1.079	440
Fort Cobb (1603-33-02)	0.045	0.006	0.045	0.805	1.138	513
Little Washita (1602-33-02)	0.041	0.054	0.068	0.815	1.189	491
South Fork (1607-33-02)	0.055	-0.009	0.056	0.621	0.698	296
Little River (1604-33-05)	0.050	0.139	0.148	0.540	0.697	513
Kenaston (2701-33-01)	0.041	0.057	0.071	0.578	0.701	191
Carman (0901-33-11)	0.068	-0.032	0.075	0.488	0.789	292
Monte Buey (1902-33-01)	0.042	-0.000	0.042	0.777	0.986	214
REMEDHUS (0301-33-02)	0.054	0.041	0.068	0.815	1.500	422
Twente (1204-33-06)	0.058	0.077	0.097	0.757	1.015	362
HOBE (6701-33-01)	0.064	-0.001	0.064	0.746	1.579	123
MAHASRI (5301-33-01)	0.031	0.010	0.033	0.865	1.078	328
Yanco (0701-33-01)	0.045	0.050	0.068	0.908	0.996	371
MEAN:	0.049	0.038	0.071	0.730	1.069	



Rotation in the scatter distribution
Results in reduction of bias

Performance Metrics: MDCA

Ref Pixel	ubRMSE	Bias	RMSE	R	Slope	N
Reynolds Creek (0401-33-02)	0.046	0.008	0.046	0.587	0.581	141
Walnut Gulch (1601-33-02)	0.030	0.029	0.041	0.814	1.373	193
TxSON-Evett (4802-33-01)	0.035	0.035	0.050	0.815	0.840	434
Fort Cobb (1603-33-02)	0.034	-0.036	0.050	0.812	0.891	474
Little Washita (1602-33-02)	0.033	0.001	0.033	0.809	0.928	444
South Fork (1607-33-02)	0.050	-0.044	0.067	0.615	0.571	282
Little River (1604-33-05)	0.046	0.087	0.099	0.517	0.541	479
Kenaston (2701-33-01)	0.038	0.022	0.044	0.557	0.546	187
Carman (0901-33-11)	0.059	-0.055	0.081	0.507	0.678	251
Monte Buey (1902-33-01)	0.036	-0.041	0.054	0.795	0.895	197
REMEDHUS (0301-33-02)	0.041	0.019	0.045	0.834	1.276	390
Twente (1204-33-06)	0.051	0.027	0.057	0.744	0.826	348
HOBE (6701-33-01)	0.051	-0.041	0.065	0.743	1.313	117
MAHASRI (5301-33-01)	0.036	0.029	0.046	0.792	1.195	266
Yanco (0701-33-01)	0.039	0.014	0.041	0.927	0.877	346
MEAN:	0.042	0.004	0.055	0.725	1.044	



~14% improvement in ubRMSD
Bias reduced to 0.004 m³/m³

Only in one site meets requirements

Eight sites meets requirements

Falls short of meeting the requirement



Albedo ω

ID	MODIS IGBP land classification	SMAP L2 Baseline	SMAP L4	MTDCA	SMOS-IC
0	Water Bodies	0			
1	Evergreen Needleleaf Forests	0.050	0.11	0.07	0.06
2	Evergreen Broadleaf Forests	0.050	0.07	0.08	0.06
3	Deciduous Needleleaf Forests	0.050	0.11	0.06	0.06
4	Deciduous Broadleaf Forests	0.050	0.09	0.07	0.06
5	Mixed Forests	0.050	0.10	0.07	0.06
6	Closed Shrublands	0.050	0.09	0.08	0.10
7	Open Shrublands	0.050	0.09	0.06	0.08
8	Woody Savannas	0.050	0.12	0.08	0.06
9	Savannas	0.080	0.13	0.07	0.10
10	Grasslands	0.050	0.06	0.06	0.10
11	Permanent Wetlands	0	0.13	0.16	0.10
12	Croplands – Average	0.050	0.10	0.10	0.12
13	Urban and Built-up Lands	0.030	0.10	0.08	0.10
14	Crop-land/Natural Vegetation Mosaics	0.065	0.14	0.09	0.12
15	Snow and Ice	0	0.09	0.11	0.10
16	Barren	0	0.07	0.02	0.12

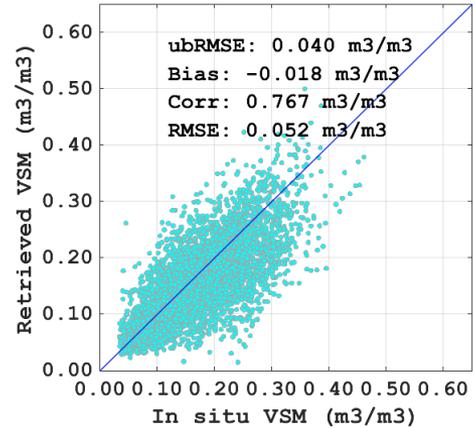
Several independent sources propose values of albedo higher than those used by SMAP



MDCA results with different omega sets

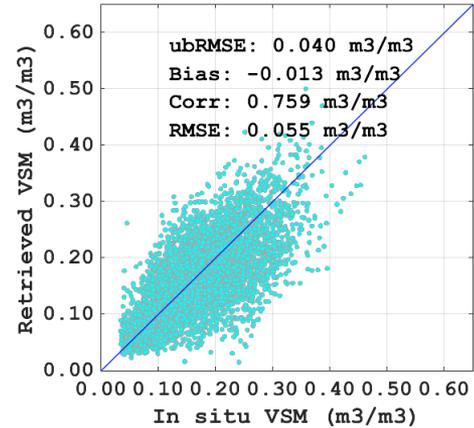
SMAP L4

6:00 AM Comparison (2015/03/31-2019/03/31)



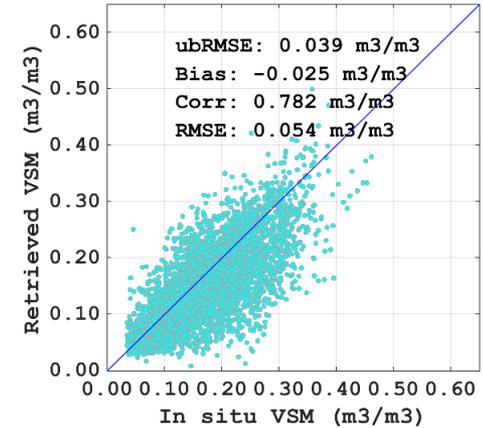
MTDCA - MIT

6:00 AM Comparison (2015/03/31-2019/03/31)



SMOS - IC

6:00 AM Comparison (2015/03/31-2019/03/31)



The use of albedo ω provided from three independent teams improves performance of MDCA over CVS



h roughness parameter

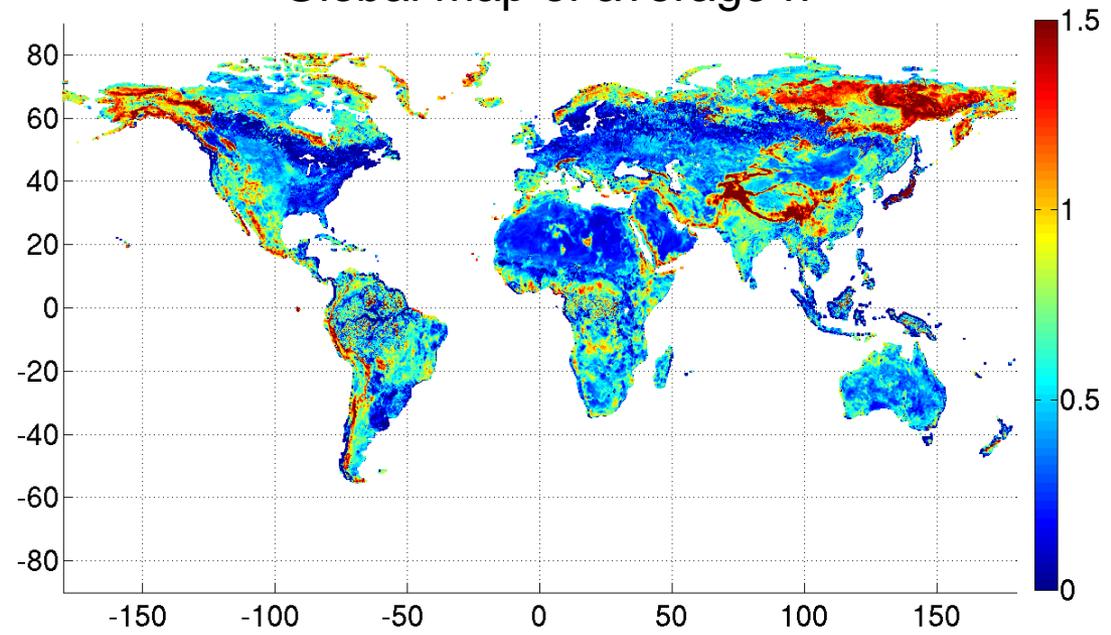
- Baseline and Wigneron model of h requires knowledge of s . Can we eliminate the dependence on s ?

We used a Dual Channel Algorithm to retrieve SM and h

$$F_h(SM, h') = [TB_V^{sim}(SM, h') - TB_V^{obs}]^2 + [TB_H^{sim}(SM, h') - TB_H^{obs}]^2$$
$$Q = 0.1771h', N = 2, \tau \text{ from NDVI.}$$

We averaged all h' for $\tau_{min} \leq \tau \leq \tau_{min} + (\tau_{max} - \tau_{min}) * 5/100$

Global map of average h



Captures expected topographical features:
The Andes in South America,
The Rocky Mountains
The Himalayan Mountains



Omega by land cover type

ID	MODIS IGBP land classification	SMAP L2 Baseline	SMAP L4 From SMOS data	MTDCA	SMOS-IC	MDCA
0	Water Bodies	0				-
1	Evergreen Needleleaf Forests	0.050	0.11	0.07	0.06	0.07
2	Evergreen Broadleaf Forests	0.050	0.07	0.08	0.06	0.07
3	Deciduous Needleleaf Forests	0.050	0.11	0.06	0.06	0.07
4	Deciduous Broadleaf Forests	0.050	0.09	0.07	0.06	0.07
5	Mixed Forests	0.050	0.10	0.07	0.06	0.07
6	Closed Shrublands	0.050	0.09	0.08	0.10	0.08
7	Open Shrublands	0.050	0.09	0.06	0.08	0.07
8	Woody Savannas	0.050	0.12	0.08	0.06	0.08
9	Savannas	0.080	0.13	0.07	0.10	0.10
10	Grasslands	0.050	0.06	0.06	0.10	0.07
11	Permanent Wetlands	0	0.13	0.16	0.10	0.10
12	Croplands – Average	0.050	0.10	0.10	0.12	0.06
13	Urban and Built-up Lands	0.030	0.10	0.08	0.10	0.08
14	Crop-land/Natural Vegetation Mosaics	0.065	0.14	0.09	0.12	0.10
15	Snow and Ice	0	0.09	0.11	0.10	0.08
16	Barren	0	0.07	0.02	0.12	0.05

We selected a new value of omega based on several independent sources and accumulation of evidence

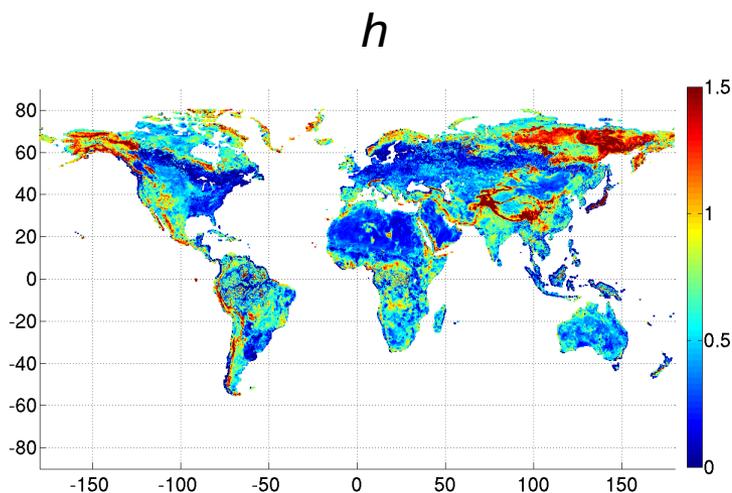


Implemented MDCA - Summary

$$F_{\tau}(SM, \tau) = [TB_V^{sim}(SM, \tau) - TB_V^{obs}]^2 + [TB_H^{sim}(SM, \tau) - TB_H^{obs}]^2$$

$$TB_p^{sim} = T_s e_p \exp(-\tau \sec \theta) + T_s (1 - \omega) [1 - \exp(-\tau \sec \theta)] [1 + r_p \exp(-\tau \sec \theta)]$$

$$r_p(\theta) = [(1 - Q)r_p^*(\theta) + Qr_q^*(\theta)] e^{(-h \cos^N(\theta))} \quad p = (V/H)$$



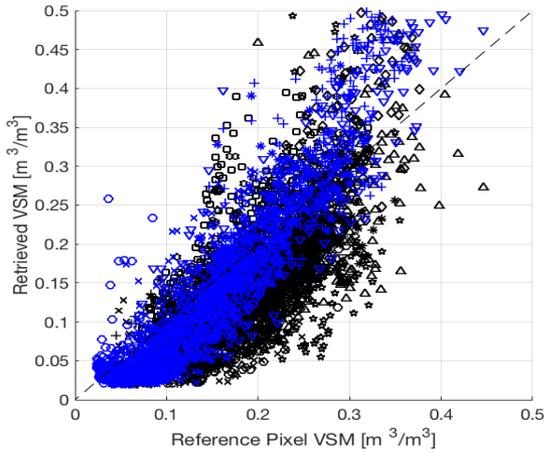
$$Q = 0.1771h, \quad N = 2$$

ID	MODIS IGBP land classification	MDCA ω
0	Water Bodies	-
1	Evergreen Needleleaf Forests	0.07
2	Evergreen Broadleaf Forests	0.07
3	Deciduous Needleleaf Forests	0.07
4	Deciduous Broadleaf Forests	0.07
5	Mixed Forests	0.07
6	Closed Shrublands	0.08
7	Open Shrublands	0.07
8	Woody Savannas	0.08
9	Savannas	0.10
10	Grasslands	0.07
11	Permanent Wetlands	0.10
12	Croplands – Average	0.06
13	Urban and Built-up Lands	0.08
14	Crop-land/Natural Vegetation Mosaics	0.10
15	Snow and Ice	0.08
16	Barren	0.05



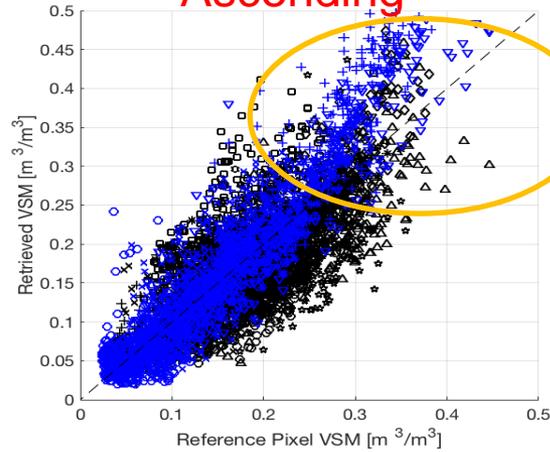
Assessment over CVS (04/01/2015 – 03/31/2019)

SCA-H

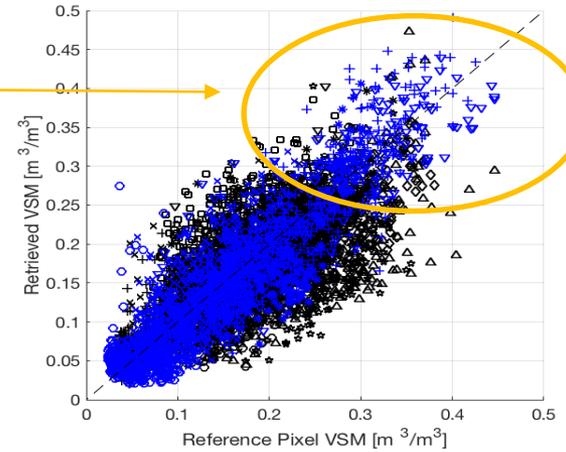


SCA-V

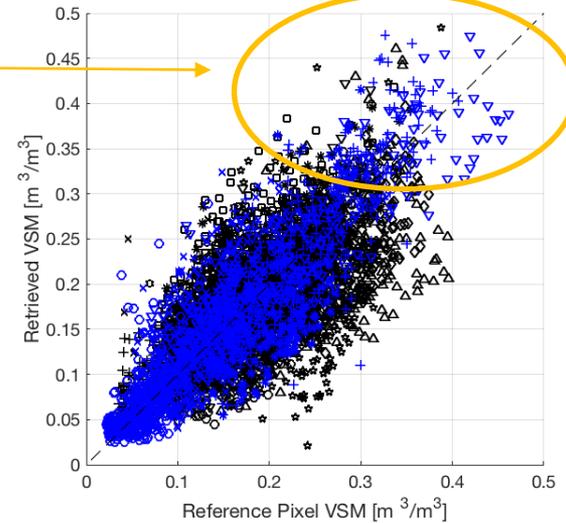
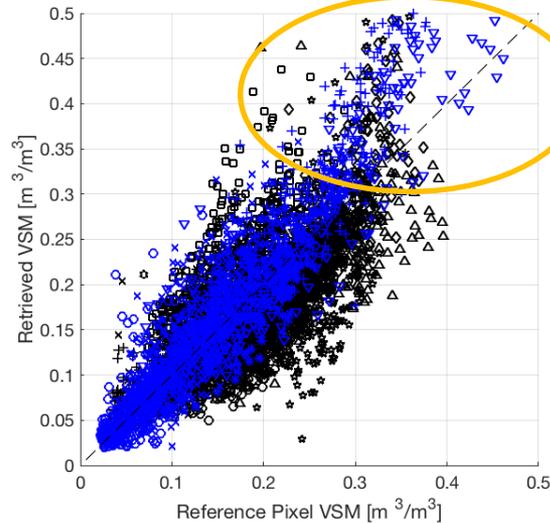
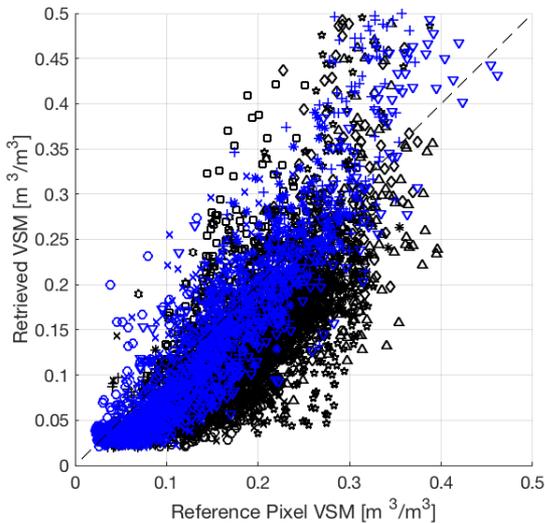
Ascending



MDCA



Descending





Summary of assessment over CVS (04/01/2015 – 03/31/2019)



Descending overpasses

Algorithm	ubRMSD (m ³ /m ³)	Bias (m ³ /m ³)	MABias (m ³ /m ³)	RMSD (m ³ /m ³)	R (m ³ /m ³)
SCA-V	0.038	-0.002	0.024	0.047	0.817
SCA-H	0.046	-0.030	0.035	0.063	0.783
DCA	0.049	0.039	0.044	0.072	0.728
DCA with WL*	0.042	0.004	N/A	0.041	0.725
DCA + WL + Omega	0.038	-0.015	0.028	0.050	0.777
MDCA	0.040	-0.007	0.026	0.050	0.772

* Wigneron + Lawrence model

- **Red** indicates overall best performance.
- **Green** indicates best performance over dual channel algorithms.
- SCA-V shows best performance over sparse networks.
- MDCA improves with respect to DCA. Low bias and ubRMSD meets requirements.



Summary of assessment over sparse network (04/01/2015 – 03/31/2019)



Descending overpasses

Algorithm	ubRMSD (m ³ /m ³)	Bias (m ³ /m ³)	MABias (m ³ /m ³)	RMSD (m ³ /m ³)	R (m ³ /m ³)
SCA-V	0.047	0.003	0.056	0.066	0.688
SCA-H	0.050	-0.036	0.065	0.077	0.673
DCA	0.056	0.057	0.080	0.094	0.588
DCA with WL*	0.052	0.024	0.068	0.079	0.591
DCA + WL + Omega	0.049	0.007	0.061	0.073	0.640
MDCA	0.049	0.008	0.059	0.070	0.660

* Wigner + Lawrence model

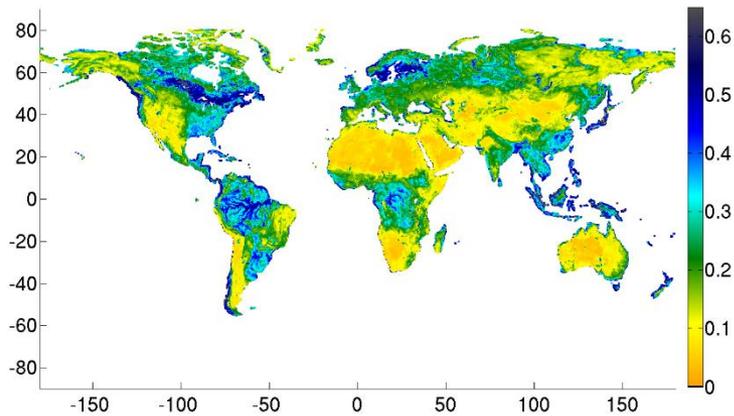
- Red indicates overall best performance.
- Green indicates best performance over dual channel algorithms.
- SCA-V shows best performance over sparse networks.
- MDCA shows best performance over all dual channel algorithms.
- MDCA 12.5% reduction in ubRMSD



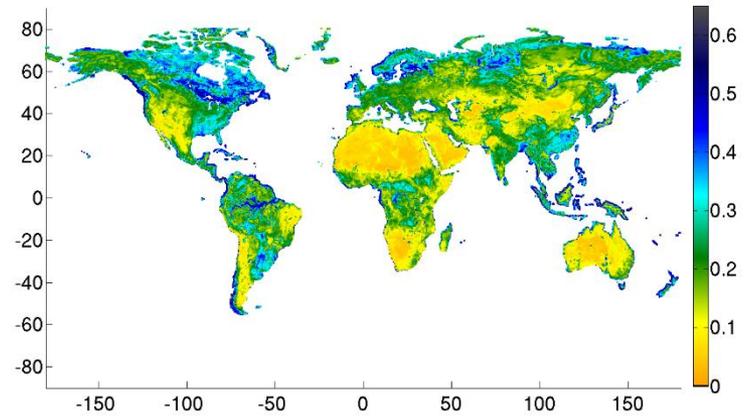
Global maps of SM 4 Years averaging (04/01/2015 – 03/31/2019)



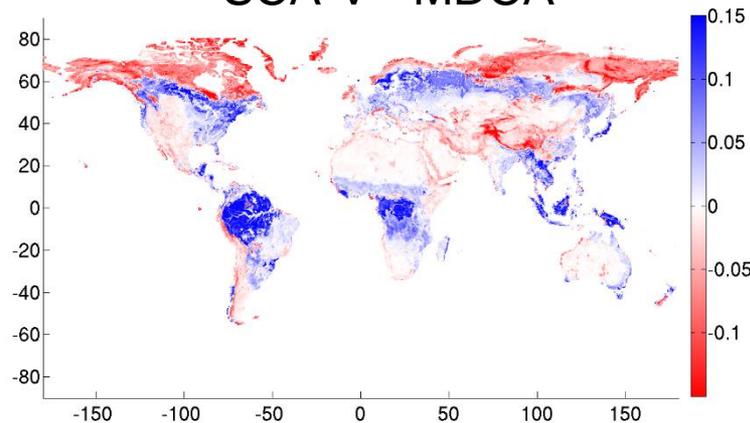
SCA-V



MDCA



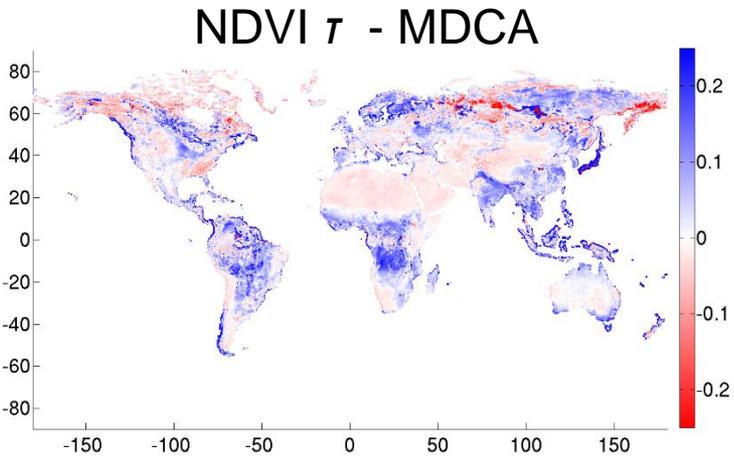
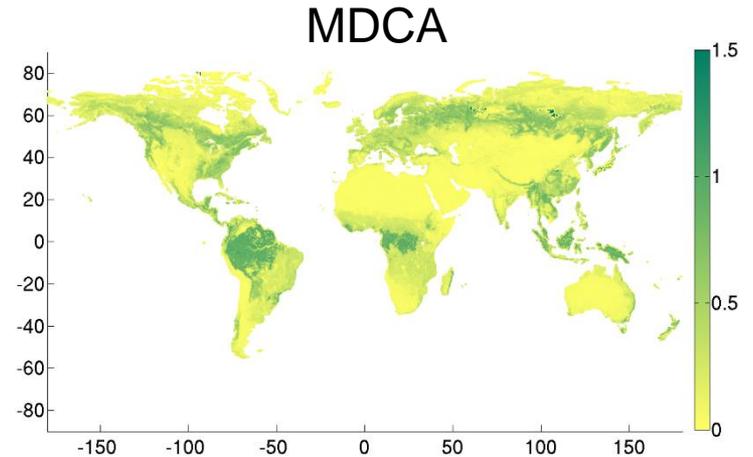
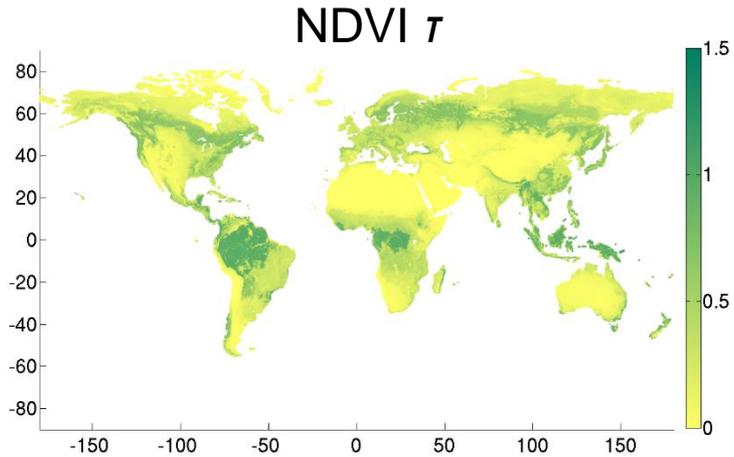
SCA-V - MDCA



- Very good agreement in barren areas.
- Open shrublands and grasslands show wetter MDCA SM retrievals.
- SCA-V retrieves higher values of SM in forested areas, woody savannas and savannas (below 50° latitude).
- Woody savannas and savannas above 50° latitude show that SCA-V retrieves lower values of SM.



Global maps of vegetation optical depth 4 Years averaging (04/01/2015 – 03/31/2019)



- Forested areas, woody savannas, savannas and croplands show predominately higher values of NDVI τ except for the east coast of US
- Barren and grasslands areas show a good agreement between NDVI and MDCA retrieved τ .



Summary



- A modified Dual-Channel algorithm (MDCA) for the retrieval of SM and vegetation optical depth was presented
 - The results were assessed over four years of collected data: (04/01/2015 – 03/31/2019)
 - MDCA outperforms DCA and SCA-H over CVS and Sparse Networks.
 - MDCA satisfies SMAP mission requirements for descending, ascending and combined overpasses.
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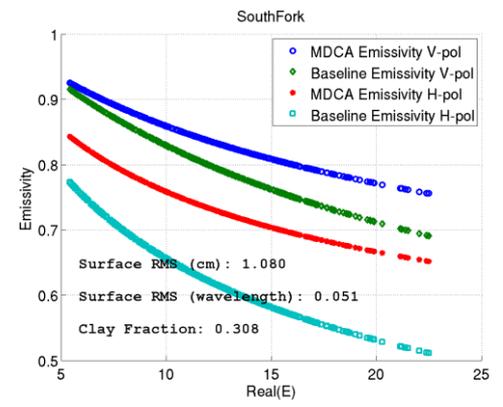
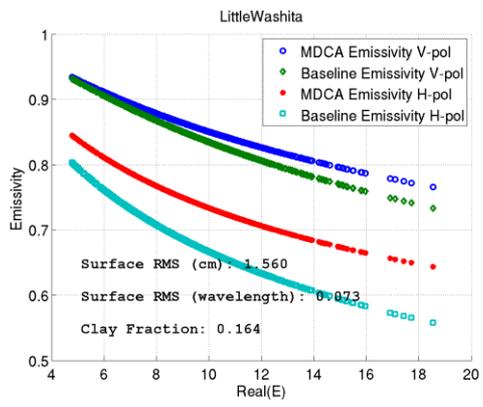
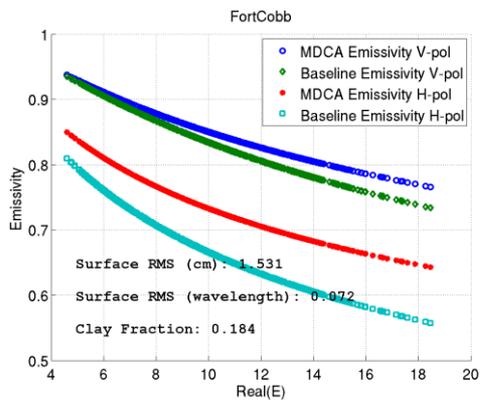
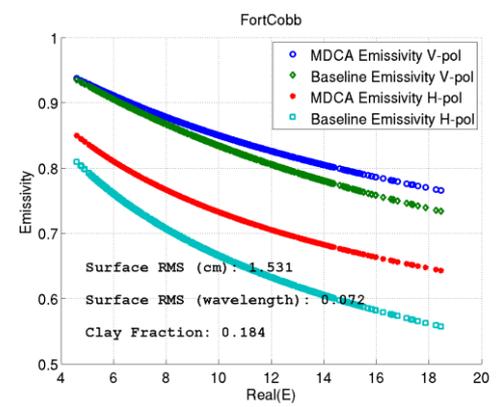
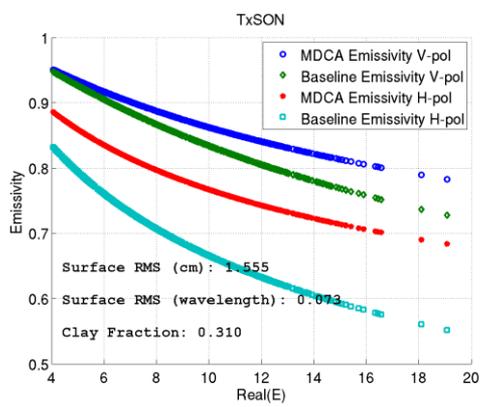
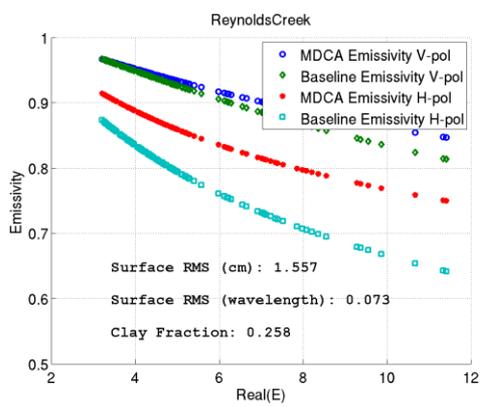


Backup



Emissivity

- MDCA emissivities are higher than those computed with baseline algorithm.
- Differences increase with increasing SM.
- MDCA H-pol emissivity shows larger differences than V-pol emissivity



Assessment over CVS

Descending overpasses (04/01/2015 – 03/31/2019)



CVS	ubRMSD (m ³ /m ³)			Bias (m ³ /m ³)			RMSD (m ³ /m ³)			R		
	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA
Reynolds Creek	0.055	0.04	0.045	0.036	-0.013	-0.002	0.065	0.042	0.046	0.592	0.653	0.046
Walnut Gulch	0.042	0.026	0.029	0.052	0.015	0.022	0.067	0.030	0.036	0.815	0.796	0.036
TxSON	0.041	0.021	0.030	0.087	-0.008	0.016	0.096	0.023	0.034	0.821	0.934	0.034
Fort Cobb	0.044	0.029	0.034	0.009	-0.047	-0.04	0.045	0.055	0.052	0.813	0.878	0.052
Little Washita	0.042	0.021	0.032	0.055	-0.018	-0.001	0.069	0.028	0.032	0.815	0.912	0.032
South Fork	0.055	0.052	0.053	-0.012	-0.038	-0.057	0.057	0.064	0.078	0.628	0.705	0.078
Little River	0.050	0.036	0.036	0.144	0.059	0.051	0.152	0.069	0.063	0.550	0.783	0.063
Kenaston	0.041	0.031	0.035	0.057	0.007	0.02	0.070	0.031	0.040	0.585	0.774	0.040
Carman	0.066	0.067	0.061	-0.022	-0.05	-0.061	0.070	0.083	0.086	0.488	0.587	0.086
Monte Buey	0.043	0.051	0.038	-0.001	-0.015	-0.039	0.043	0.053	0.054	0.777	0.860	0.054
REMEDHUS	0.053	0.042	0.041	0.038	0.017	0.016	0.065	0.045	0.044	0.818	0.845	0.044
Twente	0.059	0.054	0.049	0.078	0.045	-0.001	0.098	0.071	0.049	0.751	0.889	0.049
HOBE	0.065	0.036	0.051	0.00	-0.003	-0.046	0.065	0.036	0.069	0.755	0.860	0.069
MAHASRI	0.035	0.03	0.03	0.008	0.006	0.009	0.035	0.031	0.032	0.802	0.854	0.032
Yanco	0.046	0.039	0.038	0.064	0.014	0.008	0.079	0.041	0.039	0.915	0.932	0.039
Mean Absolute Bias				0.044	0.024	0.026						
Average	0.049	0.038	0.040	0.039	-0.002	-0.007	0.072	0.047	0.050	0.728	0.817	0.772

- Red indicates SMAP meets requirement

Assessment over CVS Ascending overpasses (04/01/2015 – 03/31/2019)



CVS	ubRMSD(m^3/m^3)			Bias (m^3/m^3)			RMSD (m^3/m^3)			R		
	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA	DCA	SCA-V	MDCA
Reynolds Creek	0.053	0.043	0.045	0.044	-0.015	-0.001	0.069	0.045	0.045	0.621	0.623	0.623
Walnut Gulch	0.038	0.024	0.028	0.034	0.003	0.009	0.051	0.024	0.029	0.730	0.751	0.745
TxSON	0.035	0.020	0.028	0.081	-0.006	0.010	0.089	0.021	0.030	0.822	0.935	0.860
Fort Cobb	0.038	0.030	0.030	-0.007	-0.049	-0.049	0.038	0.057	0.058	0.795	0.873	0.837
Little Washita	0.037	0.022	0.029	0.045	-0.012	-0.006	0.058	0.025	0.030	0.788	0.912	0.817
South Fork	0.058	0.046	0.056	-0.027	-0.044	-0.063	0.064	0.063	0.085	0.608	0.77	0.645
Little River	0.059	0.036	0.041	0.134	0.061	0.048	0.146	0.071	0.063	0.314	0.764	0.635
Kenaston	0.047	0.025	0.040	0.056	0.007	0.016	0.073	0.026	0.043	0.665	0.884	0.727
Carman	0.055	0.052	0.050	-0.031	-0.053	-0.068	0.064	0.074	0.084	0.550	0.656	0.594
Monte Buey	0.040	0.043	0.037	-0.015	-0.006	-0.048	0.043	0.043	0.061	0.773	0.917	0.775
REMEDIUS	0.050	0.041	0.041	0.027	0.007	0.007	0.057	0.041	0.041	0.817	0.834	0.810
Twente	0.050	0.052	0.043	0.062	0.05	-0.008	0.080	0.072	0.044	0.814	0.910	0.876
HOBE	0.063	0.034	0.050	0.006	0.006	-0.041	0.064	0.035	0.065	0.767	0.849	0.783
MAHASRI	0.035	0.031	0.032	0.000	0.00	0.00	0.035	0.031	0.032	0.681	0.757	0.747
Yanco	0.040	0.041	0.037	0.053	0.016	0.004	0.066	0.044	0.037	0.936	0.936	0.924
Mean Absolute Bias				0.041	0.022	0.025						
Average	0.047	0.036	0.039	0.031	-0.002	-0.013	0.066	0.045	0.050	0.712	0.825	0.760

- Red indicates SMAP meets requirement



Assessment over sparse network (04/01/2015 – 03/31/2019)



Descending (AM)	RMSD (m ³ /m ³)			ubRMSD (m ³ /m ³)			Bias (m ³ /m ³)			Mean Absolute Bias (m ³ /m ³)			R			N sites
	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	
Evergreen needleleaf forest	0.050	0.049	0.067	0.035	0.034	0.036	-0.024	0.031	0.057	0.040	0.043	0.059	0.732	0.736	0.693	2
Mixed forest	0.080	0.060	0.063	0.056	0.057	0.060	-0.057	-0.019	-0.020	0.067	0.050	0.052	0.693	0.680	0.647	1
Open shrublands	0.066	0.055	0.061	0.041	0.041	0.046	-0.042	0.000	0.018	0.054	0.044	0.05	0.580	0.593	0.583	43
Woody savannas	0.090	0.088	0.088	0.060	0.056	0.060	-0.019	0.028	0.023	0.075	0.075	0.074	0.713	0.732	0.657	19
Savannas	0.063	0.052	0.052	0.033	0.031	0.031	-0.038	-0.006	-0.014	0.055	0.045	0.046	0.874	0.876	0.870	3
Grasslands	0.093	0.072	0.072	0.051	0.050	0.054	-0.070	-0.027	-0.011	0.081	0.060	0.060	0.687	0.696	0.666	238
Croplands	0.113	0.098	0.098	0.077	0.066	0.066	-0.038	-0.011	-0.011	0.096	0.083	0.083	0.559	0.601	0.555	61
Crop/Natural vegetation mosaic	0.101	0.090	0.091	0.073	0.063	0.065	-0.025	0.017	0.007	0.083	0.076	0.076	0.579	0.644	0.636	23
Barren/Sparse	0.036	0.035	0.040	0.023	0.023	0.025	-0.015	0.014	0.024	0.031	0.030	0.035	0.644	0.633	0.638	6
Average	0.077	0.066	0.070	0.050	0.047	0.049	-0.036	0.003	0.008	0.065	0.056	0.059	0.673	0.688	0.660	396
SMAP L2SMP_E V2	0.075	0.065	0.094	0.048	0.045	0.056	-0.034	0.003	0.057	0.063	0.055	0.080	0.660	0.668	0.588	
Ascending (PM)	RMSD (m ³ /m ³)			ubRMSD (m ³ /m ³)			Bias (m ³ /m ³)			Mean Absolute Bias (m ³ /m ³)			R			N sites
	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	SCA-H	SCA-V	MDCA	
Evergreen needleleaf forest	0.052	0.055	0.078	0.037	0.036	0.042	-0.027	0.034	0.066	0.04	0.049	0.07	0.665	0.655	0.594	2
Mixed forest	0.075	0.056	0.057	0.057	0.055	0.055	-0.049	-0.013	-0.017	0.063	0.047	0.048	0.699	0.727	0.728	1
Open shrublands	0.066	0.054	0.061	0.041	0.041	0.046	-0.046	-0.003	0.016	0.055	0.044	0.049	0.569	0.560	0.535	43
Woody savannas	0.089	0.091	0.088	0.060	0.055	0.061	-0.004	0.037	0.023	0.074	0.079	0.074	0.703	0.712	0.606	19
Savannas	0.062	0.055	0.056	0.035	0.033	0.034	-0.031	-0.001	-0.013	0.053	0.048	0.049	0.868	0.850	0.835	3
Grasslands	0.090	0.072	0.073	0.051	0.049	0.053	-0.065	-0.025	-0.014	0.078	0.060	0.061	0.694	0.701	0.662	238
Croplands	0.112	0.097	0.097	0.076	0.064	0.064	-0.024	-0.006	-0.016	0.095	0.083	0.083	0.562	0.605	0.547	61
Crop/Natural vegetation mosaic	0.098	0.091	0.091	0.073	0.063	0.065	-0.001	0.030	0.007	0.081	0.078	0.077	0.565	0.633	0.604	23
Barren/Sparse	0.038	0.036	0.041	0.024	0.025	0.027	-0.018	0.014	0.025	0.032	0.031	0.035	0.557	0.514	0.496	6
Average	0.076	0.067	0.071	0.050	0.047	0.049	-0.029	0.007	0.009	0.063	0.057	0.061	0.654	0.662	0.623	396
SMAP L2SMP_E V2	0.074	0.067	0.096	0.049	0.046	0.056	-0.028	0.008	0.059	0.063	0.057	0.083	0.633	0.635	0.540	